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The ability to use Differential Global Positioning System (DGPS) to determine the position of a dynamic GPS receiver, such as would be found aboard a hydrographic survey boat, to an accuracy of one decimeter identified a related problem; e.g., the lack of a test range with instrumentation that could position a dynamic target to an accuracy of 1 cm. (An accepted rule-of-thumb is for the test instrumentation to be 10 times more accurate than the system being tested.)

This paper will present the activities that lead to establishing a test course that could be used to test high accuracy dynamic positioning systems. The various alternatives that were considered and the factors that lead to selecting terrestrial photogrammetry will be presented, and the test course itself and the photogrammetric instrumentation will be described.

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ESTABLISHMENT OF A TEST COURSE
FOR HIGH ACCURACY DYNAMIC POSITIONING SYSTEMS

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ABSTRACT

The ability to use Differential Global Positioning System (DGPS) to determine the position of a dynamic GPS receiver, such as would be found aboard a hydrographic survey boat, to an accuracy of one decimeter identified a related problem; e.g., the lack of a test range with instrumentation that could position a dynamic target to an accuracy of 1 cm. (An accepted rule-of-thumb is for the test instrumentation to be 10 times more accurate that the system being tested.)

This paper will present the activities that lead to establishing a test course that could be used to test high accuracy dynamic positioning systems. The various alternatives that were considered and the factors that lead to selecting terrestrial photogrammetry will be presented, and the test course itself and the photogrammetric instrumentation will be described.

1 INTRODUCTION

In 1988 the U.S. Army Engineer Topographic Laboratories (USAETL) conducted an experiment at Holloman Air Force Base, Alamogordo, New Mexico, in dynamic positioning using the principle of DGPS. The results of the data analysis from this test, by Dr. Clyde Goad of the Ohio State University, was that DGPS could offer a dynamic positioning system with accuracies in the centimeters range. This conclusion lead us through the following: a. If such a system can be developed, at some future time it will be developed, and b. as a service for our customers, the surveyors of the Corps of Engineers, how do we prove or disprove stated accuracy claims?

The basic problem we were addressing was the recognition that a test range with instrumentation accurate to one to two centimeters simply did not exist. The solution to this problem was obvious - we would need to develop such a test range. We then added the following constraints to the specifications for the test facility.

a. The range instrumentation system would need to use a technology that was recognized and accepted as far as accuracy was concerned.

b. The system being tested could be travelling at velocities up to 10 miles per hour.

c. The system needed to be owned by us; and capable of being operated by "non-experts".

d. The total cost of the system needed to be less than $100,000.

We considered several technologies such as laser ranging, laser ranging with an inertial platform, various optical/mechanical systems, and terrestrial

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photogrammetry. Photogrammetry was selected as the technology that best offered to meet all of our specifications. In a study performed by Dr. Kim Wong of the University of Illinois, a positional accuracy of two centimeters was considered possible using two fixed cameras viewing an area approximately 400 by 400 feet, when the vehicle carrying the system being tested was travelling at speeds up to 10 miles per hour. Dr. Wong was then asked to evaluate the use of film-based as well as charge-coupled device (CCD) cameras. We were interested in looking at a CCD based system as it offered the possibility of near real time operation. However, such a system was not available off-the-shelf, would have required the development of custom software, and had inadequate width in field of view. We therefore selected the application of the more conventional film-based system for the test course instrumentation.

The concept that we planned to implement was as follows: Two cameras, at known locations, view a designated area stereoscopically. A vehicle with the positioning system being tested is driven through the test area while logging positions. A radio link synchronizes the positioning system outputs with the camera control unit that trips the camera's shutter, thus producing photographs at the same instant in time that the positioning system logs coordinates. Using analytical photogrammetry, the true coordinates of the positioning system are determined, and these values are then compared to the test system's logged coordinates. It should be noted that if the positioning system under test uses GPS, the radio link is unnecessary as GPS time will be used to synchronize positions and photographs.

2 SYSTEM DEVELOPMENT

Following the studies performed by Dr. Wong, we contacted the Tennessee Valley Authority (TVA) who had extensive experience with close range photogrammetry, and tasked then to develop the test system. The tasks that they were to perform consisted of identifying and procuring the cameras, developing the system procedures to be implemented, performing tests to verify the concept using their own equipment and implementing the system at a designated test area and training USAETL personnel.

1.2 Test Course

A suitable location for the test course was found on the grounds of the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. The area has a clear view without obstructions for the two camera stations, favorable terrain relief for precise determination of positions in three dimensions, and the personnel of NIST would be available for validation of the camera and photogrammetric target monuments. As shown in Figure 1, the test course is an area of 400 by 450 feet. The two cameras are positioned 400 feet apart. Eight photogrammetric targets are positioned along two parallel lines within view of both cameras. The vehicle with the test positioning system travels between the parallel targets logging coordinates and simultaneously activating the cameras shutters through the radio link. The eight photogrammetric targets were designed using a four foot vertical range pole with two small white spheres, one at the top and one near the ground. Metal baffles painted flat black are positioned behind the white spheres to increase contrast in the photographs. It was also necessary to design a rigid roof rack for the vehicle because the position of an antenna cannot be determined with required accuracy from photographs. The roof rack consists of eight spheres each mounted

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on a target rod. By measuring the position of each target rod, the position of the antenna can be calculated.

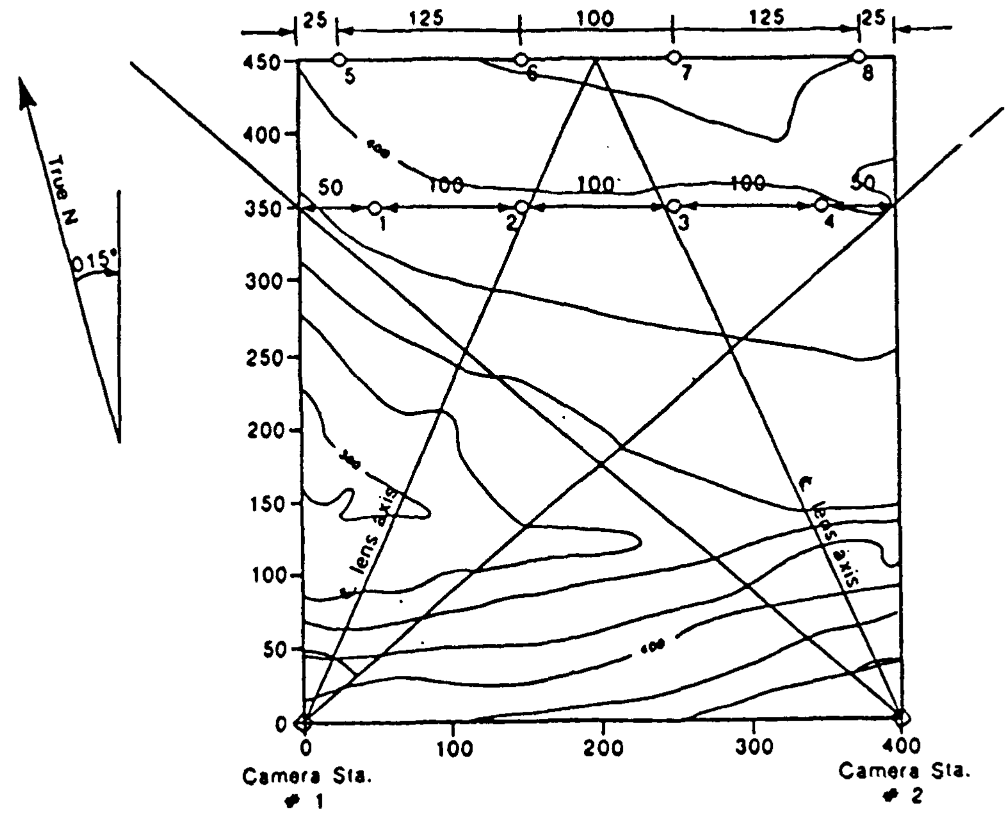

Fig. 1 Test Course Layout

2.2 Photogrammetric Cameras

A pair of Rolleimetric 6006 70-mm cameras was purchased by TVA and calibrated. The 60-mm focal length lenses were permanently affixed to the camera bodies and the focus was set permanently at infinity to improve the stability of the cameras, thereby approaching true metric capability. The calibrations by Geodetic Services, Inc., showed an rms closure of image coordinates of 5 micrometers. The cameras have a reseau grid plate and vacuum film flattening to improve accuracy. A total of 121 calibrated reseau crosses are on the plate and after several accuracy tests, the TVA determined that 9 of them were a sufficient number for this project. A true metric camera with a larger format would have achieved better results, and several such cameras were considered, but they did not have 1/500-second electronic shutters that was needed and were too expensive for our project budget.

2.3 Time Synchronization

In order to achieve an accuracy of 2 centimeters with the system under test moving at velocities of up to 10 miles per hour, the error budget requires that the time of the position determination by the system being tested and camera shutter to be accurate to 1 millisecond.

A time correlator was developed by Dr. K. S. Yang of the University of Illinois to measure the delay between the receipt of the transmitted signal and the shutter operation. This device has a panel of six rows of high intensity LEDs. Upon receiving a start signal, a set of counters begins accumulating pulses at a precise rate of 5000 hertz. Thus, each pulse represents 0.2 milliseconds of time. The top three rows of the device display the time since receipt of pulse by the time correlator, row 1 at 1X, row 2 at 10X and row 3 at 100X intervals. The bottom three rows measure exactly how long the camera shutter remains open. The LEDs in row 4 through 6 light individually in sequence with the start pulse and each stays lit for precisely 0.2 milliseconds. Thus the time the shutter remains open can be calculated from the total number of LEDs in the second group that are lit on the developed film.

Once the precise time delay from receipt of signal to shutter operation has been determined, this information is utilized with a Camera Control Unit to synchronize events. The Camera Control Unit contains a precise clock which is synchronized with the output pulse of the positioning system by observing the signals on an oscilloscope and adjusting the camera control accordingly. Then, the pulse that will trigger the camera shutter is set in advance of the second pulse by the amount determined by the time correlation. This then produces each photograph at the precise instant of the positioning system coordinate output.

3 INITIAL TEST RESULTS

The first positioning systems that were tested on our test course were Ashtech L-XII and Trimble series 4000 GPS receivers mounted within our test vehicle. The test vehicle was driven at 5 miles per hour resulting in up to four photographs during the 1-minute period to transverse the course. We also drove at 10 miles per hour which permitted one photograph per traverse. Unfortunately, we determined that some of the photographs were not accurately synchronized with the Ashtech's GPS 1-pps time tick. One test run, where all of the normal start-up problems were under control, on May 22, 1991, resulted in three photographs during the vehicle traverse, and the results are as follows:

	GPS POSITION MINUS PHOTOGRAMMETRIC POSITION					
	NORTHING		EASTING		ELEVATION	
PHOTO #	Δcm	Photo STD	Δcm	Photo STD	Δcm	Photo STD
13A	-4.08	0.41	1.01	0.44	6.43	0.34
13B	-5.43	0.61	-1.13	0.33	10.91	0.44
13C	-6.28	0.46	-2.65	0.54	9.69	0.45

At the time this paper was being written, other photographs were under process but results were not yet available.

4 CONCLUSIONS

It is generally recognized that DGPS will yield horizontal positions that are more accurate than vertical positions. This is not the case with photogrammetry, and this is shown in the test results. The deviation between photogrammetric value and GPS value are 4 to 6 cm in Northing, 1 to 2 cm in Easting, but 6 to 10 cm in elevation. The value, "Photo STD" refers to the internal accuracy of measurement of photo points only - and indicate a precision of less than 1 cm in all three dimensions. However, all that we can say at this time is that our test course instrumentation appears to be somewhere between 1 and 6 cm in horizontal position and less than 11 cm in elevation. As can be seen from our schedule below, we still have a lot of work to do. This fall and winter we will refine procedures, perhaps modify our Camera Control Unit to be more automated increasing our photographs per course traverse, rely upon the GPS clock for time-base and have the positioning system and cameras synched to this time base.

SCHEDULE:

May 1991 - Integrate Components; Perform System Tests
Summer 1991 - Test Kinematic GPS ETL Receivers
Winter 1991-1992 - Refine System; Improve User Operation
Summer 1992 - Open Test Course

Our objective was to be able to verify or refute accuracy claims for dynamic positioning systems. It now appears that the first system to be tested on our test course that the developers claim to be of decimeter accuracy - is a system that we, USAETL, are developing for the Dredging Research Program.

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